

CLEAR EDDY CURRENT FLAW IMAGE USING COMPUTERIZED TOMOGRAPHY INVERSION TECHNIQUE

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INTRODUCTION

More and more surface probes have been used instead of bobbin coils to detect smaller flaws in eddy current testing. Needs of high accuracy testing have been making eddy current testing use precise scanning of the probes. Flaw imaging has been used in eddy current testing in order to identify small flaws [1-8]. However, the eddy current testing using the conventional pancake coil probe provides only blurred images of flaws. In order to obtain clear flaw images in eddy current testing, the authors first tried to restore clear flaw images from the blurred eddy current testing images using deconvolution method. However, the deconvolution method provided only clear but rather noisy images.

Thus the authors have thought of a new method combining the computerized tomography inversion technique and a thin rectangular tangential coil which scans and rotates over the flaw. Then the authors have transformed the ECT signals into ones analogous to X-ray projections and applied CT inversion technique to the signals. The experimental results using a tangential coil and CT inversion technique have shown that the new method provides clear images with little noise of various slit-like flaws.

FLAW IMAGES IN EDDY CURRENT TESTING

Eddy current testing is conducted by scanning the coil probe over the test materials. The flaw image is supposed to make it easier to evaluate the flaw characteristics. However, eddy current testing provides only blurred images of flaws because the eddy current induced in the test materials by a coil probe spreads over a larger area than the coil diameter as shown in Figure 1. It is obviously difficult to evaluate flaw characteristics from blurred flaw images. Flaw characterization needs clear flaw images. Thus the authors first tried to restore flaw images from blurred eddy current testing flaw images by deconvolution method.

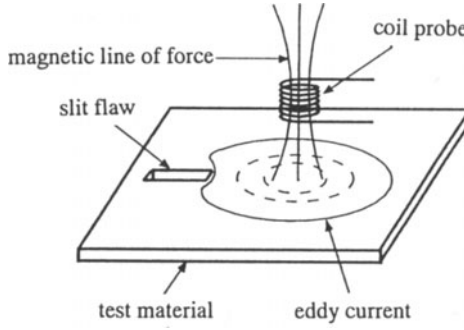


Figure 1 Flaw image degradation in eddy current testing.

DECONVOLUTION METHOD

Eddy current testing provides blurred flaw image $b(x,y)$ while the test probe scans over a flaw $d(x,y)$ where (x,y) denotes two dimensional position. This process can be expressed by a linear system as shown in Figure 2. If an input image $d(x,y)$ is applied to a linear system with point spread function $p(x,y)$, the resultant degraded output image $b(x,y)$ is given by the following convolution [9].

$$b(x,y) = d(x,y) \otimes p(x,y) \quad (1)$$

Fourier transform converts Equation (1) into the following frequency domain equation.

$$B(u,v) = D(u,v) \cdot P(u,v) \quad (2)$$

where (u,v) denotes spatial frequency domain and $B(u,v)$, $D(u,v)$, and $P(u,v)$ are Fourier transforms of $b(x,y)$, $d(x,y)$, and $p(x,y)$ respectively. Equation (2) leads to the following equation.

$$D(u,v) = B(u,v) / P(u,v) \quad (3)$$

From Equation (3), if function $P(u,v)$ is known, the input image Fourier transform $D(u,v)$ is derived from the output image Fourier transform $B(u,v)$. Image restoration can be conducted by using the transfer function $F(u,v)$ of a linear system defined by the following equation if the noise is negligibly small.

$$F(u,v) = 1 / P(u,v) \quad (4)$$

Thus once the function $F(u,v)$ is derived, a restored flaw image Fourier transform $R(u,v)$ can be obtained from the blurred flaw image Fourier transform $B(u,v)$ by the following equation as shown in Figure 3.

$$R(u,v) = B(u,v) \cdot F(u,v) \quad (5)$$

Inverse Fourier transform converts Fourier transform $R(u,v)$ to the clear restored image $r(x,y)$.

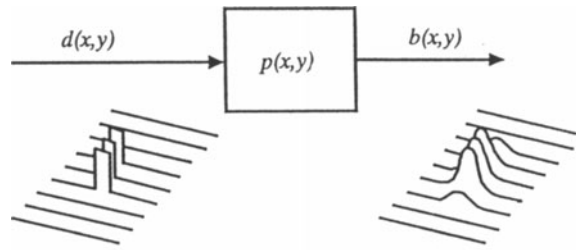


Figure 2 Linear system and image degradation.

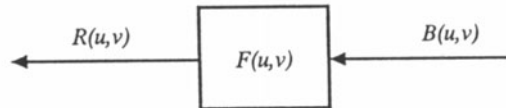


Figure 3 Image restoration by deconvolution.

EXPERIMENTAL RESULTS OF DECONVOLUTION METHOD

Figure 4 shows the circular test coil used for the eddy current testing. The test materials of brass plates are 1.5 mm thick and have discharge-machined flaws. The authors derived the point spread function from the eddy current signal of a short slit flaw of 2 mm after they had found that a small drill hole does not work because there is no linear relationship between a drill hole signal and slit flaw signals.

Figure 5 and 6 show the image restoration results by the deconvolution method. As seen from these figures, the deconvolution method provides only clear but noisy flaw images. The authors have found that the noise has higher frequency components and the higher components cannot be discarded in order to obtain clear flaw images.

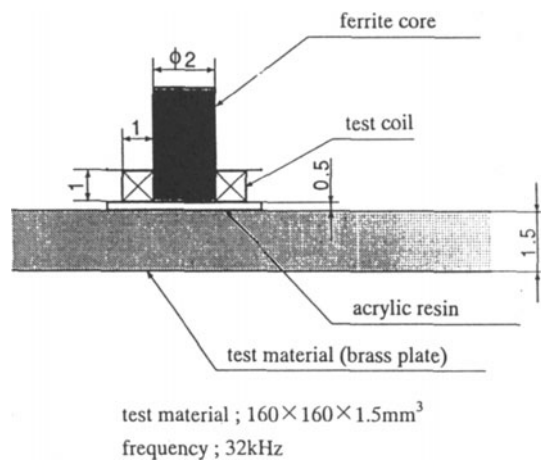


Figure 4 Circular test coil and the test material.

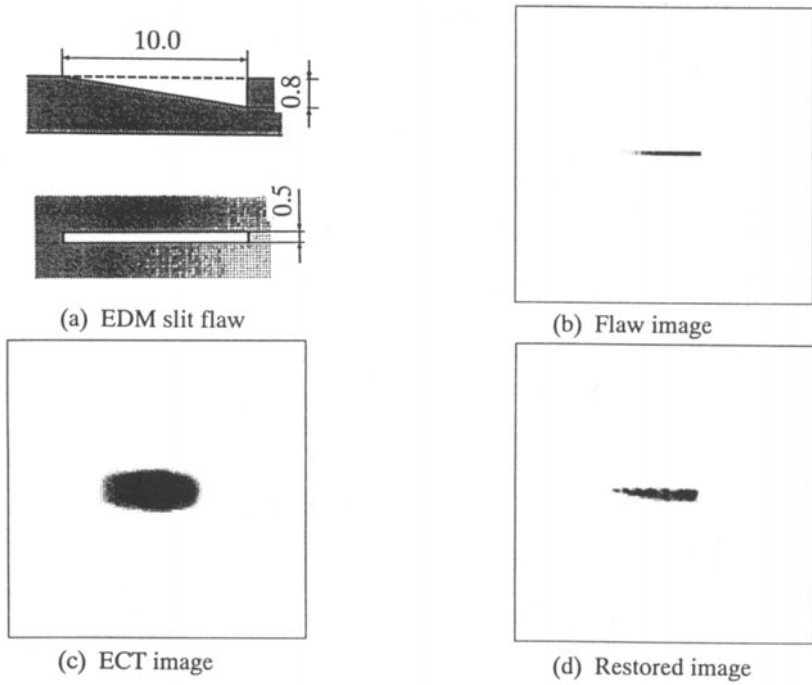


Figure 5 Flaw image restoration by deconvolution method (a saw cut flaw).

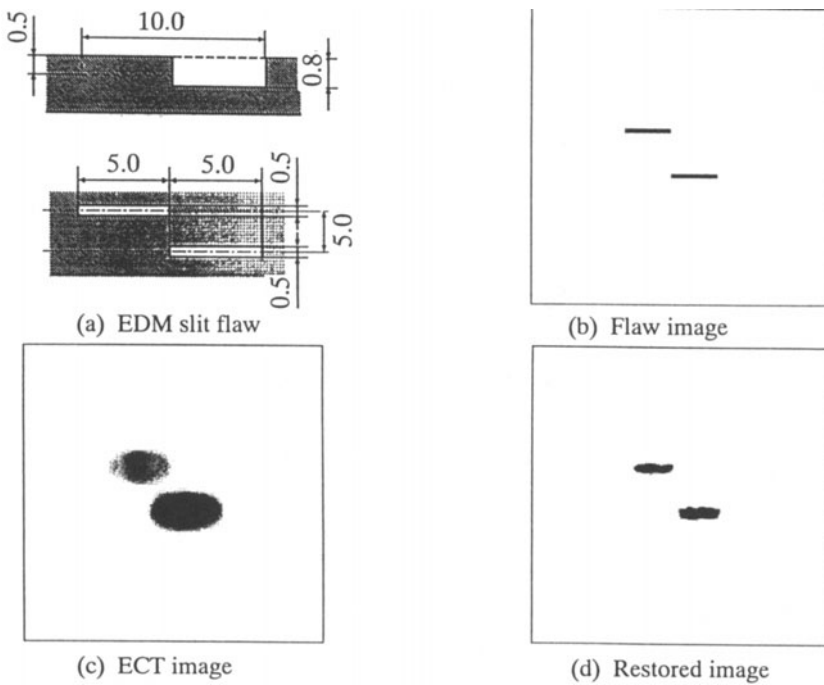


Figure 6 Flaw image restoration by deconvolution method (two slit flaws).

RADON TRANSFORM IN X-RAY CT

Let us consider a material which has attenuation coefficient $F(x,y)$ of X-ray as shown in Figure 7. When a X-ray is applied to the material in y_r direction and scanned in x_r direction, the projection to x_r axis is given by following Radon transform.

$$P(x_r) = \int F(x_r, y_r) \cdot dy_r \quad (6)$$

Thus the X-ray projections are derived by the line integral in the X-ray direction. Rotations and scans of the X-ray beam produce a group of projections which are converted into a tomography of the material by CT inversion technique. The authors wanted to apply this CT inversion method to eddy current testing to obtain clear ECT flaw images.

FLAW SIGNALS GENERATED BY A TANGENTIAL COIL

The authors have used a thin tangential coil which induces a straight eddy current beam as shown in Figure 8. Thus the authors thought that, if the tangential coil has a small winding cross section and is scanned and rotated over a flaw in a test material, the resultant signals would be analogous to projections in X-ray CT. It is assumed that the tangential coil is longer than slit flaws. The authors have also assumed that the flaw signal from the tangential coil is proportional to the flaw depth. Thus, when the eddy current is induced in y_r direction and scanned in x_r direction, the resultant ECT flaw signal is derived by the following equation

$$S(x_r) = k \cdot D(x_r, y_{rm}) \quad (7)$$

where $D(x,y)$ is the flaw depth, y_{rm} is the y_r value at the maximum flaw depth, and k is constant. The authors noticed that the ECT flaw signal given by Equation (7) is totally different from Radon transform in X-ray CT given by Equation (6).

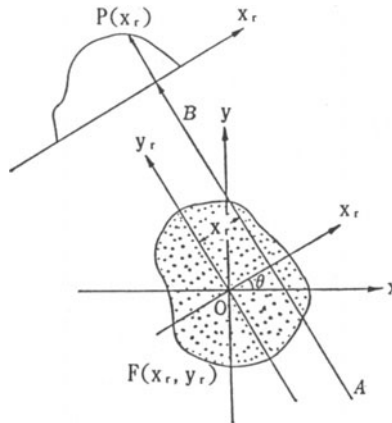


Figure 7 X-ray CT projections.

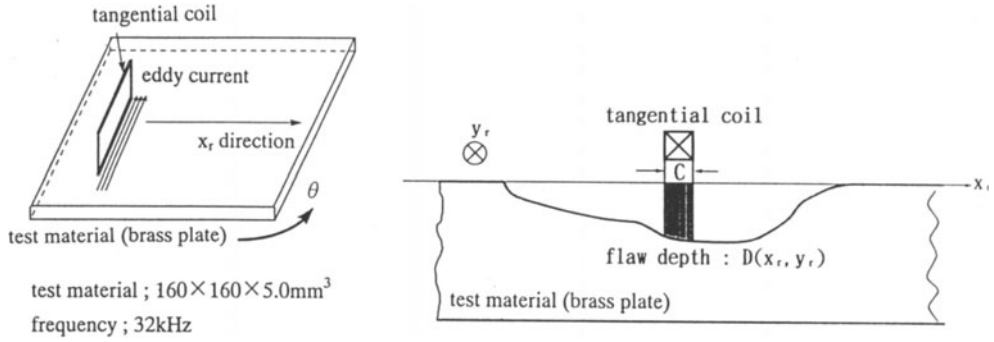


Figure 8 Eddy current induced in test material.

ECT SIGNAL TRANSFORM

Then the authors have thought of transforming the ECT signals in order to make the signals analogous to X-ray CT projections[10]. When the tangential coil is scanned in y_r direction, the ECT signal is expressed by the following equation.

$$S(y_r) = k \cdot D(x_{rm}, y_r) \quad (8)$$

Signals given by Equations (7) and (8) are combined by the following equation.

$$E(x_r) = S(x_r) \cdot \int S(y_r) \cdot dy_r = K \cdot \int D(x_r, y_{rm}) \cdot D(x_{rm}, y_r) \cdot dy_r \quad (9)$$

where K is constant. The resultant signal contains the information on the flaw depth $D(x, y)$ and is obtained by the line integrals along the lines perpendicular to the scanning directions of the tangential coil which is analogous to Radon transform given by Equation (6). Thus the authors have thought that CT inversion technique can be applied to ECT signals transformed by Equation (9) in order to obtain clear ECT flaw images.

EXPERIMENTAL RESULTS OF CT INVERSION

The experiments have been conducted using brass plates at the test frequency of 32 kHz. The size of the tangential coil is 50 mm long and 25 mm high. The eddy current signals were taken at each rotation angle of 0.72 degrees and each scan pitch of 0.5 mm. A pancake coil of 4 mm diameter was also used to conduct the conventional eddy current testing.

Figure 9 and 10 show the experimental results of ECT flaw image by CT inversion technique. The figures show the actual flaw images, the ECT flaw images obtained by the pancake coil, and the CT inversion flaw images. Those figures apparently show that CT inversion images are clearer than those obtained by the conventional pancake coil.

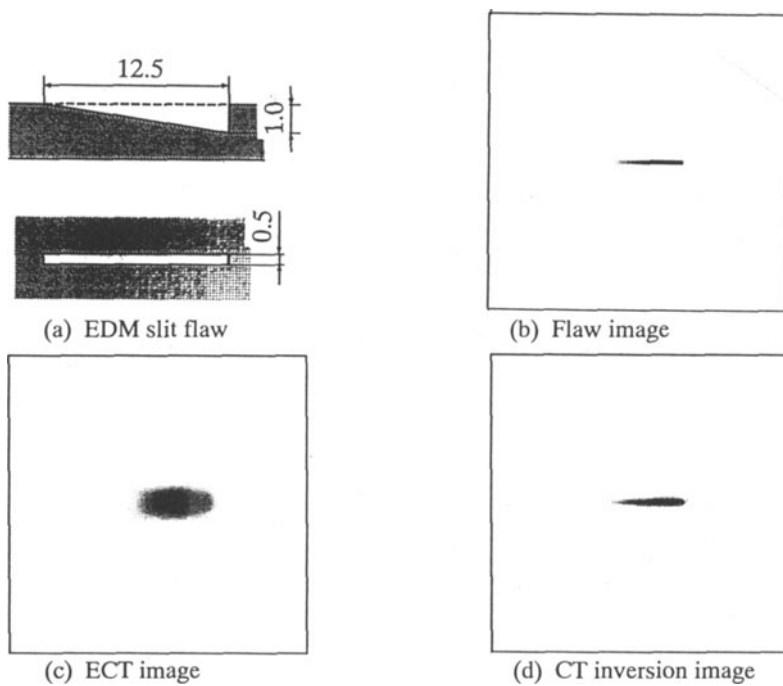


Figure 9 ECT flaw image by CT inversion (a saw depth flaw).

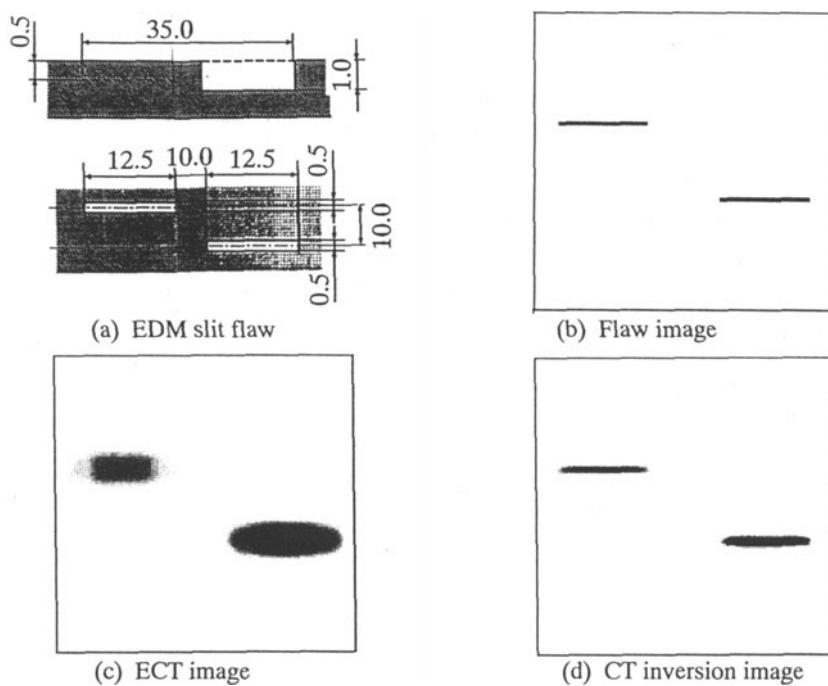


Figure 10 ECT flaw image by CT inversion (two slit flaws).

CONCLUSION

This paper has reported the deconvolution method and CT inversion to obtain clear ECT flaw images. The deconvolution method can restore only clear but noisy flaw images from blurred eddy current testing images when the transfer function is derived using a very short slit flaw. The method combining a tangential coil probe and CT inversion technique provides clearer slit flaw images with less noise. The authors think that clear flaw images will help to evaluate flaws quantitatively in eddy current testing. Further research is needed to construct clear images of other flaws than slit flaws.

REFERENCES

1. R.O. McCary, D.W. Oliver, K.H. Silverstein, J.D. Young, "Eddy Current Imaging", IEEE Trans. Magnetics, Vol.Mag-20, No.5, pp1986-1988, 1984
2. R.E. Joynson, R.O. McCary, D.W. Oliver, K.H. Silverstein, L.L. Thumhart, "Eddy Current Imaging of Surface-Breaking Structure", IEEE Trans. Magnetics, Vol.Mag-22, No.5, pp1260-1262, 1986
3. T.W. Guettinger, K. Grotz, H. Wezel, "Eddy Current Imaging", Materials Evaluation, Vol.51, No.4, pp444-451, 1993
4. B. Benoist, P. Attaoui, R. La, R. Lengelle, R. Gaillard, J. Reucht, "Edge Detection on Eddy Current Image to Increase Defect Characterization", Review of Progress in QNDE, Vol.15A, pp829-836, Plenum Press New York, 1996
5. T. Sollier, J.M. Philippe, H. Maury, D. Villard, "Eddy Current Image Restoration Using the Grohong Parametrical Model", Review of Progress in QNDE, Vol.15A, pp837-844, Plenum Press New York, 1996
6. D.C.Copley : Eddy Current Imaging for Defect Characterization, Review of Progress in QNDE, 2, pp1527-1540, 1983
7. A.J.Bahr, B.A.Auld : An Electromagnetic Model for Eddy Current Imaging, J. of nondestructive Evaluation, Vol.7, No.1, pp71-77, 1988
8. T.W.Guettinger, K.Grotz, H.Wezel : Eddy Current Imaging, Materials Evaluation, Vol.51, No.4, pp444-451, 1993
9. T.S.Huang, W.F.Schreiber, O.J.Tretiak : Image Processing, Proc. of IEEE, Vol.59, No.11, pp1586-1609, 1971
10. H.Hoshikawa and K.Koyama : Clearer ECT Flaw Image Utilizing CT Inversion Technique, Review of Progress in QNDE, 16A, pp821-828, 1997